Comparative Performance of Sugarcane Bagasse and Black Polyethylene as Mulch for Squash (*Cucurbita pepo* L.) Production

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Abstract

Louisiana processed 11.7 million mt of sugarcane in 2016, producing 1.47 million mt of raw sugar and an estimated 3.5 million mt of bagasse. Sugarcane bagasse is the fibrous material remaining after removing the sucrose, water, and other impurities (filter mud) from the millable sugarcane. Typically, Louisiana sugarcane mills burn a portion of the bagasse to heat boilers to steam power the mill for grinding and sugar processing. The balance of the bagasse is stored at the sugar mill where it accumulates in immense piles. Research was conducted in 2015 and 2016 to investigate the use of sugarcane bagasse as a natural mulch for vegetable production. The field experiment compared sugarcane bagasse mulch, black plastic mulch, and no mulch (control) for suitable mulching treatments for squash (*Cucurbita pepo* L.) production. The black plastic mulch produced significantly greater marketable fruits/plant, fruit number, and total yield (kg/ha) across years compared to the sugarcane bagasse mulch. The sugarcane bagasse mulch and the no mulch control were not significantly different for these same parameters. Black plastic also produced heaver fruit (g/fruit) than the sugarcane bagasse mulch and the control in 2015. The black plastic mulch produced greater yields due to the greater cumulative growing degree days (CGDD) received compared to the sugarcane bagasse mulch and no mulch control. The sugarcane bagasse mulch tended to mitigate temperature extremes by serving as a soil insulator. Future research should investigate the potential deleterious impact, if any, of the sugarcane bagasse on soil microbes, C/N ratio, soil pH, and allelopathy, which might adversely influence cucurbit growth.

Keywords: accumulative growing degree days, agricultural by-products, bagasse, certified organic, natural mulches, squash, sugarcane

1. Introduction

1.1 Sugarcane Bagasse Uses

In 2016, Louisiana sugarcane farmers harvested 11.7 million mt millable sugarcane from 163,000 ha, producing 1.47 million mt of raw sugar and an estimated 3.5 million mt of bagasse (American Sugar Cane League, 2017). Global sugar production in 2016 was over 171 million mt of raw sugar, which resulted in over 300 million mt of bagasse (United States Department of Agriculture, 2017). Bagasse is the fibrous by-products produced when removing the sugar, water, and other superfluous materials from the millable sugarcane. On the dry weight basis, bagasse is primarily composed of cellulose (40-50%), hemicellulose (30-35%), and lignin (20-30%) (Amin, 2011; Cardona et al., 2010; A. R. F. Drummond & I. W. Drummond, 1996; Martin et al., 2007; Pandey et al., 2000; Sales & Lima, 2010). As a plentiful by-product, sugarcane bagasse has been successfully used as a fiber source for paper and construction board production (Amin, 2011; Xin et al., 2002). Nigam (1990) and Pandey et al. (2000) investigated its use as a cattle feed, while others have used in as an amendment to potting media (Jhurree-Dussoruth et al., 2011; Trochoulias et al., 1990). There is also current and past interest in using the bagasse a source for value added products (*i.e.* pigments, enzymes, amino acids, and drugs) (Pandey et al., 2000). The most common use for the bagasse by the sugarcane industry is as an energy source (thermal conversion and ethanol) (Badger, 2002; Kilicaslan et al., 1999; Martin et al., 2007; Peng et al., 2009; Sun & Cheng, 2002).

Due to the abundant surplus supply of bagasse at Louisiana sugarcane sugar mills, research was initiated to determine additional uses for sugarcane bagasse. The long frost-free growing season, 230-290 days a year, in southern Louisiana that favors sugarcane production also provides an ideal environment for vegetable

production. Plastic and organic mulches are used in vegetable production to enhance soil temperatures, retain soil moisture, prevent soil erosion, and decrease pest infestations. The objective of the research was to determine the feasibility of using sugarcane bagasse as planting mulch for field produced vegetables.

2. Material and Methods

2.1 Experimental Design

The field experiment compared sugarcane bagasse mulch, black plastic mulch, and no mulch (control) for suitable mulching treatments for squash (*Cucurbita pepo* L.) production. The experiment was conducted in the spring of 2015 and 2016 at the USDA, ARS, Sugarcane Research Center, Houma, LA, USA on a Cancienne silt loam and Cancienne silty clay loam soil, 0 to 1% slope. The experiment was laid out as a randomized complete block design with 3 mulching treatments, 4 replications, 3 rows/plot (5.3 m wide), 1.8 m row spacing, and 7.6 m plot lengths. Prior to planting each year the soil was fertilized with 65 kg/ha of N-P-K (April 6, 2015 and April 5, 2016), tilled, and made into 91 cm wide 18-cm high raised beds on 1.8 m row centers. A 13 mm irrigation drip line with inline emitters every 30.5 cm was placed on the top of each raised bed just off of the center line for the entire study. The sugarcane bagasse was applied to the top of the raised bed to a depth of 7.6 cm (88 mt/ha). The sugarcane bagasse mulch was obtained from the Lafourche Sugar Corp. sugar mill, Thibodaux, LA. The 1.2 m wide black 1 mil plastic mulch was placed on top of the raised beds and secured on each side and both ends by soil between the raised beds (April 9, 2015 and April 6, 2016). The control plots, which had no mulch, received a broadcast application (187 L/ha) of pendemethalin (1.7 kg ai/ha) and metolachlor (1.7 kg ai/ha), XR8002VS nozzle. Following the application of the mulches, yellow squash variety 'Enterprise' seeds were direct-seeded 45 cm apart the length of each plot on May 4, 2015 and May 5, 2016. Squash plant stands were thinned to a consistent plant population of 12,300 plants/ha (45 cm between plants within rows) (Figure 1).

2.2 Temperature and Cumulative Growing Degree Day Calculations

Weather data were obtained from a nearby on-farm weather station that recorded environmental variables every 10 seconds and averaged every minute to provide daily maximum and minimum temperatures (Ardoyne Farm, USDA, ARS, Sugarcane Research Unit, Shriever, LA, USA). Although, ambient air temperatures are typically used to determine degree days, it is understood that the soil temperatures might be different (Yousef et al., 2013), therefore, data loggers were used in 2015 to monitor soil temperatures at 2.54 cm. Two soil temperature data loggers (HOBO® Pendant Temperature Data Logger UA-001-08, Onset Computer Corporation, Pocasset, MA, USA) were place within each plot at a depth 2.54 cm (seeding depth) and recorded temperatures every 10 minutes.

The following formula was used to estimate cumulative growing degree days (GDD); CGDD = $[(T_{max} + T_{min})/2] - T_{base}$. GDD were calculated using a base temperature (T_{base}) of 8 °C for squash (Coolong, 2017; Maynard & Hochmuth, 2007; NeSmith & Hoogenboom, 1994; Yousef et al., 2013) and a daily maximum temperature (T_{max}) of 32 °C (Coolong, 2017; NeSmith, 1997; NeSmith & Hoogenboom, 1994; Yousef et al., 2013). The daily minimum temperature (T_{min}) was used for all calculations.

Soil moisture was maintained during the experiment by rainfall supplemented with drip irrigation. Squash fruit was harvested three times a week for a total of 19 harvests, June 3 to July 15, 2015 and June 6 to July 20, 2016 from the center row of each 3 row plot. The fruit was separated into marketable (unblemished, 13 to 20 cm long) and unmarketable (blemished) fruit, counted, and weighed. All data were subjected to ANOVA and mean separation using LSD with P = 0.05 (SAS Inc., SAS, Ver. 9.0, Cary, NC).

Figure 1. Squash plants growing on black plastic mulch, sugarcane bagasse mulch, and without mulch (bare soil), left, middle, and right, respectively

3. Results and Discussion

3.1 Statistical Analysis

There were no significant year by treatment interactions for the squash production parameters of marketable and non-marketable average plant production (fruit/plant), fruit number (fruit/ha), and yield (kg/ha), therefore, these parameters will be discussed across treatment and years (Tables 3-6). The statistical analysis did detect a significant year by treatment interaction for marketable fruit weight (g/fruit), therefore, fruit weight will be discussed by treatment for each year, 2015 and 2016 (Table 7).

3.2 Temperature Data and Cumulative Growing Degrees Days

Minimum, maximum, and average air temperatures were very similar across years (Table 1). The CGDD was slightly higher in 2016 compared to 2015, 63 CGDD, a 4.5% difference, but it must be noted that 2016 had 4 additional days, 77 d compared to 73 d, to accumulate heat units compared to 2015 (Table 1). When averaged over the entire growing periods, planting to final harvest, the daily average degree days (DADD) for the two years were 19.1 and 18.9, 2015 and 2016, respectively (Table 1).

Table 1. Average minimum, maximum, average air temperatures, cumulative growing degree days CGDD, and the daily average degree days (DADD) from planting to final harvest, 73 days and 77 days, for 2015 and 2016, respectively

Year	Minimum[Z]	Maximum[Y]	Average[X]	CGDD[W]	DADD[V]
	(°C)	(°C)	(°C)		
2015[U]	21.7	31.4	26.1	1,394	19.1
2016[T]	21.5	31.6	26.0	1,457	18.9

Note. [Z]Daily average minimum air temperatures from planting to the final harvest; [Y]Daily average maximum air temperatures from planting to the final harvest; [X]Daily average air temperatures from planting to the final harvest; [W]Cumulative degree days, CGDD = $[(T_{max} + T_{min})/2] - T_{base}$, where T_{base} and T_{min} = 8 °C, T_{max} limited to 32 °C; [V]Cumulative degree days average across days from planting to final harvest for each year; [U]2015: Planting to final harvest = 73 days; [T]2016: Planting to final harvest = 77 days.

Although the 2015 and 2016 minimum, maximum, and average air temperatures were equivalent across years, which resulted in similar CGDD and DADD values (Table 1), the mulching treatments significantly impacted the minimum, maximum, and average soil temperatures at 2.54 cm depth (Table 2). The differences in soil temperatures, therefore, significantly influenced CGDD and DADD among mulching treatments (Table 2). Black plastic produced higher minimum soil temperatures than the control (no mulch), but was not different than the sugarcane bagasse (Table 2). In all soil related parameters (maximum and average soil temperatures, CGDD and DADD) the black plastic was significantly greater than either the sugarcane mulch or the no mulch control (Table 2). The no mulch control was not significantly different than the sugarcane bagasse for average soil temperature, which might be expected due to the differences between the treatments for minimum and maximum soil temperatures, where the control had numerically slightly lower minimum temperatures, but not significantly different, and significantly greater maximum temperatures compared to the sugarcane bagasse mulch (Table 2).

It is interesting to note the differences between temperature parameters for the 2015 air temperatures and the soil temperatures (Tables 1 and 2). Numerically, the soil temperatures for all mulching treatments were greater than the 2015 air temperatures, while only marginally greater for maximum temperatures for black plastic (33.5 °C vs. 31.4 °C) and the control (32.5 °C vs. 31.4 °C) (Tables 1 and 2). There were 29 days (40%) and 39 days (51%) in 2015 and 2016, respectively, that exceeded T_{max} (32 °C) for air temperatures, compared to 45 days (61%), 11 days (15%), and 34 days (47%) for 2015 where the soil temperatures exceeded T_{max} (32 °C) for the black plastic, sugarcane bagasse, and the control, respectively (data not shown). The number of days exceeding T_{max} also corresponded to the maximum soil temperatures for the mulches in 2015 (Table 2). Yet, the cumulative impact resulted in a large difference between the soil CGDD compared to the air temperature CGDD (Tables 1 and 2). Although, soil temperatures were not collected in 2016, it would be reasonable to expect a similar impact on soil parameters in 2016 due to the almost identical air temperatures parameters between years (Table 1).

Table 2. Average minimum, maximum, average soil temperatures at 2.54 cm, cumulative growing degree days CGDD, and the daily average degree days (DADD) from planting to final harvest, 73 days, for 2015

Mulch Treatment	Minimum[Z]	Maximum[Y]	Average[X]	CGDD[Z]	DADD[Y]
	(°C)	(°C)	(°C)		
Black Plastic	26.5 a[T]	33.5 a	29.4 a	2,748 a	37.6 a
Sugarcane Bagasse	26.0 ab	30.9 c	27.7 b	2,571 c	35.2 c
Control (No Mulch)	25.2 b	32.5 b	27.9 b	2,666 b	36.5 b

Note. [Z]Daily average minimum soil temperatures at 2.54 cm from planning to the final harvest; [Y]Daily average maximum soil temperatures at 2.54 cm from planning to the final harvest; [X]Daily average soil temperatures from planting to the final harvest; [Z]Cumulative degree days, CGDD = $[(T_{max} + T_{min})/2] − T_{base}$, where T_{base} and T_{min} = 8 °C, T_{max} limited to 32 °C; [Y]Cumulative degree days average across days from planting to final harvest for 2015; [V]2015: Planting to final harvest = 73 days; [U]2016: Planting to final harvest = 77 days; [T]Means in a column followed by the same lower case letter are not significantly different at P ≤ 0.05, ANOVA.

3.3 Marketable Plant Production (fruit/plant), Fruit Number (fruit/ha), and Yield (kg/ha) Averaged across 2015 and 2016

Marketable fruits per plant, fruit number, and yield weight were significantly greater for the black plastic mulch compared to the sugarcane bagasse mulch averaged across years, and greater than the control for fruits per plant and fruit number (Table 3). The control (no mulch) was not significantly different from the sugarcane mulch across these parameters (Table 3).

Table 3. Impact of the mulch type (black plastic, sugarcane bagasse, and control (no mulch) on marketable yellow squash production in Louisiana averaged across years, 2015 and 2016

Mulch Treatment	Fruit Parameters		Yield
	(fruit/plant)	(fruit/ha)	(kg/ha)
Black Plastic	15.95 a[z]	196,195 a	39,621 a
Sugarcane Bagasse	12.23 b	150,375 b	28,738 b
Control (No Mulch)	12.84 b	150,375 b	31,613 ab

Note. [Z]Means in a column followed by the same lower case letter are not significantly different at P ≤ 0.05, ANOVA.

There were significant differences between years, 2015 and 2016, for marketable fruits per plant and fruit number, with 2016 producing more fruit per plant and total fruit number than in 2015, but with greater, but not significantly different total yield (kg/ha) (Table 4).

Table 4. Impact of growing season, 2015 and 2016, averaged across the three mulching treatments (plastic, bagasse, and control) on marketable yellow squash production in Louisiana

| Year | Fruit Parameters | | Yield |
	(fruit/plant)	(fruit/ha)	(kg/ha)
2015	11.825 b^z	145,455 b	30,315 a
2016	15.517 a	190,865 a	36,332 a

Note. ^{Z}Means in a column followed by the same lower case letter are not significantly different at P ≤ 0.05, ANOVA.

3.4 Non-Marketable Plant Production (fruit/plant), Fruit Number (fruit/ha), and Yield (kg/ha) Averaged across 2015 and 2016

Unlike the marketable fruit, there were no significant differences among the mulching treatments for fruit per plant, fruit number, or fruit yield (Table 5). Although numerically there was a tendency for greater fruit loss, non-marketable fruit, for the black plastic, the values were not significantly greater (Table 5) and were likely due to the greater overall fruit production by the black plastic mulch (Table 3).

Table 5. Impact of the mulch type (black plastic, sugarcane bagasse, and no mulch/control) on non-marketable yellow squash production in Louisiana averaged across years, 2015 and 2016

| Mulch Treatment | Fruit Parameters | | Yield |
	(fruit/plant)	(fruit/ha)	(kg/ha)
Black Plastic	0.40 a^z	4,920 a	1,400 a
Sugarcane Bagasse	0.26 a	3,229 a	690 a
Control (No Mulch)	0.31 a	3,844 a	639 a

Note. ^{Z}Means in a column followed by the same lower case letter are not significantly different at P ≤ 0.05, ANOVA.

Non-marketable fruit production (fruit/plant, fruit/ha, and kg/ha) followed the same trend as the marketable fruit data (Table 6). Non-marketable fruit losses for fruit/plant and fruit/ha were greater in 2016 compared to 2015, while the total yield (kg/ha) was not significantly different. Non-marketable fruit losses in 2015 averaged near 1.5% of the marketable yields, while in 2016 the non-marketable fruit losses were at least 3% (calculated values), but still within acceptable ranges.

Table 6. Impact of growing season, 2015 and 2016, averaged across the three mulching treatments (plastic, bagasse, and control) on non-marketable yellow squash production in Louisiana

| Year | Fruit Parameters | | Yield |
	(fruit/plant)	(fruit/ha)	(kg/ha)
2015	0.16 b^z	1,948 b	452 a
2016	0.49 a	6,048 a	1,367 a

Note. ^{Z}Means in a column followed by the same lower case letter are not significantly different at P ≤ 0.05, ANOVA.

3.5 Marketable and Non-Marketable Fruit Weight (g/fruit) by Mulching Treatment for 2015 and 2016

Statistical analysis detected a significant year by treatment interaction (P ≤ 0.05) for marketable fruit weight (g/fruit), but not for non-marketable fruit weight, although marketable and non-marketable fruit weight did vary between years among the mulching treatments (Table 7). In 2016 there was not a significant difference among

mulching treatments for both marketable and non-marketable fruit. In 2015 the black plastic mulch produced heavier marketable fruits than the sugarcane bagasse mulch, but was not significantly different than the control. The non-marketable fruit for the black plastic were heavier than those for the sugarcane bagasse mulch and the control (Table 7).

Table 7. Impact of the mulch type (black plastic, sugarcane bagasse, and control/mulch) on marketable and non-marketable yellow squash fruit weight (g/fruit) by year, 2015 and 2016

Mulch Treatment	Marketable[z]	Non-marketable[y]
	(g/fruit)	(g/fruit)
2015		
Black Plastic	220 a[x]	295 a
Sugarcane Bagasse	184 b	102 b
Control (No Mulch)	210 ab	101 b
2016		
Black Plastic	186 a[x]	251 a
Sugarcane Bagasse	194 a	183 a
Control (No Mulch)	190 a	170 a

Note. [z]Significant year by treatment intereaction at $P \leq 0.05$ for marketable fruit weight (g/fruit). [y]No significant year by treatment interaction at $P \leq 0.05$ for non-marketable fruit weight (g/fruit). [x]Means in a column within years followed by the same lower case letter are not significantly different at $P \leq 0.05$, ANOVA.

3.6 Pest Control and General Plant Appearances

Weeds, insects, and diseases were not an issue in the experiment. The weeds were controlled by either the pre-emergence herbicides, mulches, or by hand-weeding, and no damaging infestation of insects or diseases were observed. In general, the squash plants in the black plastic treatment appeared more robust, followed by the no mulch control, and lastly by sugarcane bagasse mulch. During both years the sugarcane bagasse mulched plants were a lighter green in color, tending to a yellow tinge (Figure 1).

4. Conclusions

The black plastic mulch produced significantly greater marketable fruit/plant, fruit number, and total yield (kg/ha) across years compared to the sugarcane bagasse mulch (Table 3). The sugarcane bagasse mulch and the no mulch control were not significantly different for these same parameters (Table 3). Black plastic also produced heaver fruit (g/fruit) than the sugarcane bagasse mulch or the no mulch control in 2015 (Table 7). The greater yields produced by the black plastic mulch were likely larger due to the greater CGDD and DADD compared to the sugarcane bagasse mulch and no mulch control, which resulted from greater absorption and retention of heat units during the growing season (Table 2) (NeSmith, 1997; NeSmith & Hoogenboom, 1994). The sugarcane bagasse mulch tended to mitigate temperature extremes by serving as a soil insulator (Table 2).

In addition to the direct impact of cumulative growing degree days, other factors may have attributed to the yield differences between the black plastic mulch and the sugarcane bagasse mulch. These factors include the influence of carbon to nitrogen ratio (C/N), pH, and allelopathy. The tendency of the sugarcane bagasse mulch squash plants to become yellowish during the growing season may be a result the high C:N ratio resulted from the direct contact of the sugarcane bagasse and the soil surface. Bagasse has high percentages cellulose (40-50%), hemicellulose (30-35%) and lignin (20-30%) (Amin, 2011; Cardona et al., 2010; A. R. F. Drummond & I. W. Drummond, 1996; Martin et al., 2007; Pandey et al., 2000; Sales & Lima, 2010), resulting in a reported 100:1 C/N ratio (Meunchang et al., 2005). High C/N ratios such as 100, can adversely impact the microbial activity at the soil and interface, resulting in binding up of more nitrogen, which becomes less available to the crop plant (Meunchang et al., 2005). The less than optimum nitrogen availability may have caused the sugarcane bagasse mulched plants to become yellowish and therefore less productive.

The low sugarcane bagasse pH (4.1) may have adversely impacted the soil's microbial populations decreasing nitrogen availability or plant nutrient uptake (Meunchang et al., 2005), therefore, adversely affecting squash growth and production ,which requires an optimum pH of 6.0 to 6.5 (Kemble et al., 2005).

Lastly, the leaching or the microbial breakdown of the bagasse may have had an allelopathic (toxic) impact on the squash plants (Facelli & Pickett, 1991; Rice, 1984; Rodrigues et al., 2001). Numerous researches have

documented the presence of allelopathic chemicals in sugarcane leaves (De Carvalho et al., 2005; Singh et al., 2003; Viator et al., 2006) and straw (Sampietro et al., 2007; Sampietro et al., 2005; Sampietro & Vattuone, 2006a, 2006b; Wang et al., 1967). Rodrigues et al. (2001) documented that the breakdown of sugarcane bagasse lignocellulosic material produced toxic compounds that inhibit cellular growth.

Although the additional heat units were the greatest contributing growth and production factor for the squash plants produced with the black plastic, further research should involve a closer examination of the potential impact of the sugarcane bagasse on soil microbes, C/N ratio, soil pH, and allelopathy. An economic analysis of the costs and benefits of the use of black plastic and sugarcane bagasse would also provide valuable information to a producer.

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